

# **Desert Research and Technology Studies exposure of Lotus coated electrodynamic shield samples – Part II**

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## **ABSTRACT**

The passive Lotus dust mitigation coating currently being developed at NASA's Goddard Space Flight Center (GSFC), was selected by the Habitation Demonstration Unit Deep Space Habitat (HDU-DSH) for participation in the 2011 Desert Research and Technology Studies (D-RaTS). Based on the unique surface architecture of the Lotus leaf, the nano-engineered Lotus coating seeks to replicate these structures on space flight and habitation surfaces. By decreasing both the surface energy and area for particle attachment, the Lotus coating greatly diminishes dust accumulation on surfaces. This is a problem that can be encountered on lunar, Martian, and asteroid missions. Two different application methods of this coating were tested in summer 2011 at the D-RaTS site: the wet chemistry applied version and combustion chemical vapor deposition (CCVD) applied version. These Lotus coatings, along with two common thermal control coatings, were combined with the active dust mitigation electrodynamic shield (EDS) technology developed at Kennedy Space Center (KSC). The EDS technology uses an electrified grid to remove dust particles from the surface of a Kapton™ substrate. The Lotus coating and thermal control coatings were applied to these Kapton™ substrates for testing. The combination of these two innovations was theorized to be an applicable countermeasure for addressing dust accumulation during long-duration human space exploration. This theory was tested and characterized prior to, during, and after D-RaTS exposure.

## **KEYWORD LIST**

Coating; Hydrophobic; Dust; Mitigation; Reflectivity; Contact angle

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## 1 INTRODUCTION

For the second year, active and passive dust mitigation technologies were tested at NASA's Desert Research and Technology Studies (D-RaTS) event in Black Point Lava Flow, AZ. From late August to mid September 2011, Electrodynamic Dust Shields (EDS) and Lotus coated samples were exposed to the desert dust environment. Goddard Space Flight Center (GSFC) provided the Lotus coating for the EDS technology which was supplied by Kennedy Space Center (KSC). Samples were mounted on door 4 of the large scale Pressurized Excursion Module (PEM) door. The PEM is part of the Habitat Demonstration Unit Deep Space Habitat (HDU-DSH) project. The HDU-DSH seeks to integrate and test concepts and technologies which could help to further understand alternative mission habitats and requirements. The EDS and Lotus coated samples played an integral part in determining how dust from the surrounding environment could impact the radiative and optical properties of thermal control coatings.

The Lotus coating is a "passive dust mitigation technology that relies on intrinsic self-cleaning and anti-contamination properties" in order to stay dust-free in a dusty environment<sup>1</sup>. The EDS is an active dust mitigation technology which uses a traveling electrodynamic wave to direct particles to specific location along the surface of a sample<sup>2</sup>. These technologies were theorized to work synergistically to remove dust particles from sensitive coatings. Radiative and optical property measurements were performed in the field and later characterized by GSFC coatings engineers to determine the effectiveness of these technologies.

Figure 1: HDU-DSH PEM at D-RaTS in Black Point Lava Flow, AZ



## 2 BACKGROUND

The 2011 D-RaTS demonstration involved the placement of four 14X19” EDS panels on door 4 for the PEM. One of these 14X19” EDS panels had been previously coated by GSFC Coatings Application Specialists with A276, white polyurethane thermal control coating. Two of these panels, including the A276 coated panel, had the Lotus coating applied as a top layer coating. Also placed on the door were two 8X10” EDS panels also with the Lotus coating as a top layer. One of these panels was also coated with A276. All EDS panels consist of a metalized grid between two laminated 5 mil Kapton™ sheets through which an electric field can be applied with a two-phase electrode configuration<sup>2</sup>. By charging the dust particles on the surface of the samples, the particles will be compelled to move in the same direction off the sample. In conjunction with the unique surface architecture of the Lotus coating, dust mitigation properties should be enhanced.

The Lotus coating has the ability to repel water and dust by creating a super hydrophobic boundary between dust particles and the coating. This boundary reduces the surface energy and area that is required for particle adhesion. Two different methods of Lotus coating application were tested on the PEM. The Lotus coating applied to the EDS sheets was applied using combustion chemical vapor deposition (CCVD) method in which the coating is flame sprayed onto the surface. Four other samples were exposed on the PEM door with which a wet chemistry method was employed to apply the Lotus coating. These four samples were 2x2” aluminum substrates with the AZ Technology’s Z93 white, silicate thermal control coating, applied. All exposed and control samples along with coating configurations are listed in Table 1. Figure 2 shows door 4 of the HDU-DSH PEM with the dust mitigation experiment panels mounted, facing outward.

While at the D-RaTS test site, KSC personnel activated the EDS panels several times for functional operations. Dust was applied to the surfaces of the EDS panels prior to activation using a paint brush and JSC-1A lunar simulant. Video was captured of the electrified EDS panels removing visible dust particles. Also, GSFC coatings engineers traveled twice to D-RaTS, once at the beginning and once at the end of exposure, to take microscopic images and solar absorptance measurements on all of the samples. Only solar absorptance measurements and microscope image capturing were performed at the D-RaTS test site due to the portable nature of the measuring instruments. Several days worth of measurements exist documenting the condition of the panels. At the conclusion of the D-RaTS exposure, the panels and aluminum samples were removed from the PEM and transported back to GSFC for final characterization.

Final characterization at GSFC consisted of solar absorptance measurements, confocal imaging, surface roughness analysis, contact angle measurements, and microscopic image capturing. These final measurements as well as in-situ measurements will be compared with characterization performed on the panels prior to D-RaTS exposure and characterization performed on control samples.

Table 1: Sample IDs and Coating Configuration of D-RaTS 2011 samples

Sample ID	Substrate	Size	Electrodynamic Shield Technology (EDS)	Thermal Control Coating	Lotus Coating
L1	Kapton™	14X19”	Yes	A276	CCVD Method
L2	Kapton™	14X19”	Yes	A276	CCVD Method
L3	Kapton™	14X19”	Yes	None	CCVD Method
L4 – Control	Kapton™	14X19”	Yes	None	No

<b>L5 – Control</b>	Kapton™	14X19"	Yes	None	No
<b>L6</b>	Kapton™	14X19"	Yes	None	No
<b>L7</b>	Kapton™	14X19"	Yes	None	No
<b>2010_03_08A</b>	Kapton™	8X10"	Yes	A276	CCVD Method
<b>2010_03_24_D2</b>	Kapton™	8X10"	Yes	None	CCVD Method
<b>F1T5033011</b>	Aluminum	2X2"	No	Z93	Wet Chemistry Method
<b>F1T7033011</b>	Aluminum	2X2"	No	Z93	Wet Chemistry Method
<b>F1T8033011</b>	Aluminum	2X2"	No	Z93	Wet Chemistry Method
<b>F2T7033011</b>	Aluminum	2X2"	No	Z93	Wet Chemistry Method

Figure 2: HDU-DSH PEM with Lotus experiment mounted on Door 4



### 3 TEST METHOD

#### 3.1 Contact angle

Contact angle was measured using a VCA-1000 Optima Goniometer made by Analytical Technology Group (AST). The operator uses the provided syringe to drop a single droplet of regular tap water onto the surface of the sample. A video camera records an image of the droplet. The system uses a software package to determine the contact angle, the surface energy, and surface tension through automatic and dynamic calculations. An assumption of the droplet geometry, whether it is spherical or ellipsoidal, is made based on the image. With this information, the angle in which the liquid contacts the solid surface can be calculated. A coating is determined to be hydrophobic when the contact angle is greater than 90°. A super-hydrophobic surface is defined as having a contact angle larger than 150°. Water was the only liquid used in our testing however other liquids, such as solvents, may be used as well.

### **3.2 Reflectivity**

The AZ Technology's LPSR-300 instrument was used to perform the reflectance measurements and solar absorptance calculations. The reflectance measurements followed the ASTM E903-82 standard test method. The LPSR-300 measures the reflectance of the sample's surface for a spectral range of 250 nm to 2800 nm, at a 15° angle of incidence. The instrument's measurement of accuracy is  $\pm 0.02$  for  $\alpha$  values.

### **3.3 Confocal imaging**

Confocal imaging was performed on an Olympus LEXT OLS-3100IR 408nm confocal laser scanning microscope. This microscope allows for nondestructive 3D image capturing of surfaces. The confocal microscope has five objectives from 5X to 100X with an optical zoom of 1X to 6X and a total magnification of 120X to 14400X. The microscope uses the built in imaging software, analySIS, to determine surface roughness of the image with resolution to 15 $\mu$ m.

### **3.4 Dino-Lite imaging**

A Dino-Lite series AM413ZTS polarized portable digital microscope and camera was used for both live imaging and image capturing. The AM413ZTS series microscope has a zoom range of 10X to 220X with a magnification of 10X to 55X. This microscope is specifically designed for field applications with a 6mm working distance, a built in polarizing kit and a "Micro-Touch" trigger button for capturing instant real time, live images. A Dino-Lite series AM413T5 portable digital microscope and camera was also used for both living imaging and image capturing. The AM413T5 series microscope has a fixed focus magnification of 500X and a "Micro-Touch" trigger button for capturing instant real time, live images.

## **4 RESULTS**

### **4.1 Contact angle measurements**

Contact angle measurements were performed on all of the samples prior to D-RaTS exposure as well as after the complete D-RaTS exposure. Real-time contact angle measurements could not be performed at the test site however due to the importable nature of the measuring instrument.

Kapton™ generally has slightly hydrophilic properties with an average contact angle of 76°. By applying the A276 thermal control coating, the hydrophobicity of the Kapton™ samples increases slightly to an average of 84°. After the CCVD application of the Lotus coating to the Kapton™ substrates and to the A276 coated Kapton™ substrates, the hydrophobicity increases dramatically to the superhydrophobic range of 149°. This is the range necessary to achieve maximum dust mitigation properties. Also Z93 coated aluminum samples were measured prior the wet chemistry application of the Lotus coating. This coating is extremely hydrophilic and will not allow for contact angle measurements to be made. When water droplets from the goniometer are dropped onto a Z93 coated surface, the droplets are immediately absorbed into the surface. Therefore no contact angles were recorded in Table 2 for these samples. After the wet chemistry method application of the Lotus coating, the surface of these Z93 coated aluminum samples becomes superhydrophobic demonstrating contact angle of over 150°.

Post D-RaTS contact angle measurements were performed immediately after the samples returned to GSFC by coatings engineers. For the CCVD applied Lotus coating with A276 coated Kapton™ samples, the contact angles after exposure fell, on average, by 43°. While still technically in the hydrophobic range (contact angle  $\geq 90^\circ$ ), these

samples showed contact angle degradation due to exposure and handling. Post D-RaTS contact angle measurements performed on the CCVD applied Lotus coating with just Kapton™ samples demonstrated similar results. These samples were also still in the hydrophobic range post exposure but are not considered superhydrophobic. Post D-RaTS contact angle measurements of just Kapton™ substrates without any Lotus coating application demonstrated mixed results. Most of the samples had slightly increased contact angle measurements post exposure possibly due to dust and rain water build up on the surface. Even with this increase in contact angle, these samples were still well below the superhydrophobic threshold.

The samples which performed the best post D-RaTS exposure were the wet chemistry method Lotus coating with Z93 on aluminum samples. After exposure, the contact angles for these samples decreased only, on average, by 2°. This decrease could be within the error of the instrument as well as dependent on the measurement location. Also, due to the size and substrate of these samples, handling is more convenient and thus is not as much of a degradation concern as is with the Kapton™ samples.

Table 2 below displays the contact angle measurements of the samples pre-Lotus coating, post-Lotus coating and post D-RaTS as well as the overall change in contact angle from post-Lotus coating to post exposure. The figures below are goniometer captured contact angle measurements from several of the D-RaTS exposed samples, pre and post exposure.

Several samples listed in Table 2 indicate that contact angle measurements were performed on representative samples. Contact angles on the large EDS samples could not be performed prior to exposure due to their size and inability to fit in the measuring apparatus. In order to measure the samples, the samples would have had to be bent causing potential damage to both the Lotus coating and the EDS. Smaller representative samples were coated using the samples process as the larger samples and were used in these instances. After exposure, bending the samples was no longer a concern and the samples were able to be bent to fit in the goniometer.

Table 2: Contact Angle Measurements - Pre-Lotus Coating, Post-Lotus Coating and Post D-RaTS Exposure

Sample ID	Coating Configuration	Pre-Lotus Coating Contact Angle (°)*	Post-Lotus Coating Contact Angle (°)*	Post-D-RaTS Contact Angle (°)*	Δ Contact Angle (Post-D-RATS – Post-Lotus) (°)
L1	A276/EDS/Kapton™	84**	149**	102	-47.3
L2	A276/EDS/Kapton™	84**	149**	112	-39.5
L3	EDS/Kapton™	76**	146**	N/A	N/A
L4 – Control	EDS/Kapton™	76**	76**	92	16.0
L5 – Control	EDS/Kapton™	76**	76**	85	9.0
L6	EDS/Kapton™	76**	76**	94	-12.0
L7	EDS/Kapton™	76**	76**	70	4.0
2010_03_08A	A276/EDS/Kapton™	84**	149	130	-18.6
2010_03_24_D2	EDS/Kapton™	76**	153	96	-56.5
F1T5033011	Z93/Al	N/A	152	152	-0.5

<b>F1T7033011</b>	Z93/Al		152**	155	<b>3.0</b>
<b>F1T8033011</b>	Z93/Al		153	151	<b>-2.0</b>
<b>F2T7033011</b>	Z93/Al		153	151	<b>-2.0</b>

\*Contact angle is average of left contact angle and right contact angle of water droplet

\*\*Contact angle of a representative sample



Figure 3: 2010\_03\_24\_D2 Contact Angle - Left: Pre-D-RaTS Exposure - Contact Angle =  $153^\circ$ ; Right: Post-D-RaTS Exposure - Contact Angle =  $83^\circ$  ( $96^\circ$  average)

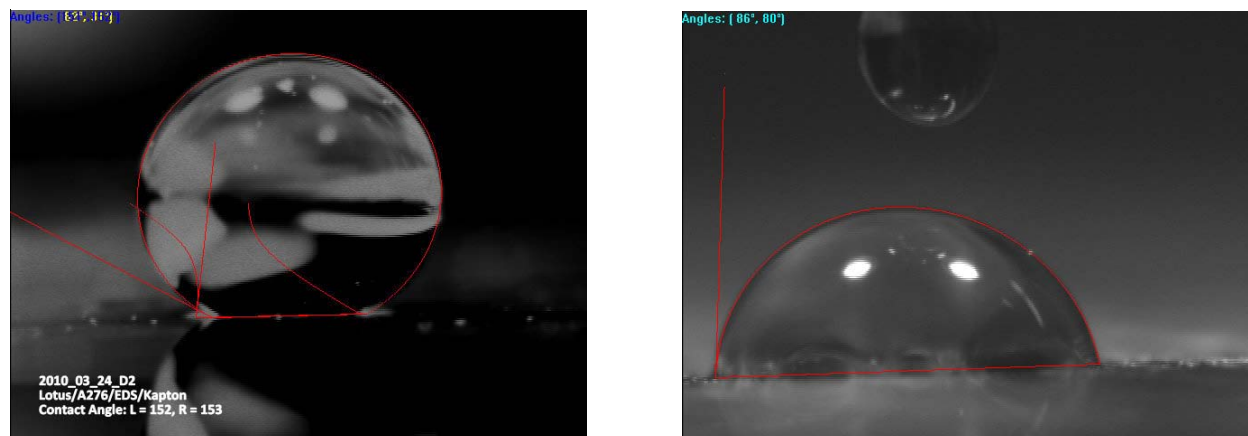


Figure 4: 2010\_03\_08A Contact Angle - Left: Pre-D-RaTS Exposure - Contact Angle =  $149^\circ$ ; Right: Post-D-RaTS Exposure - Contact Angle =  $141^\circ$  ( $130^\circ$  average)

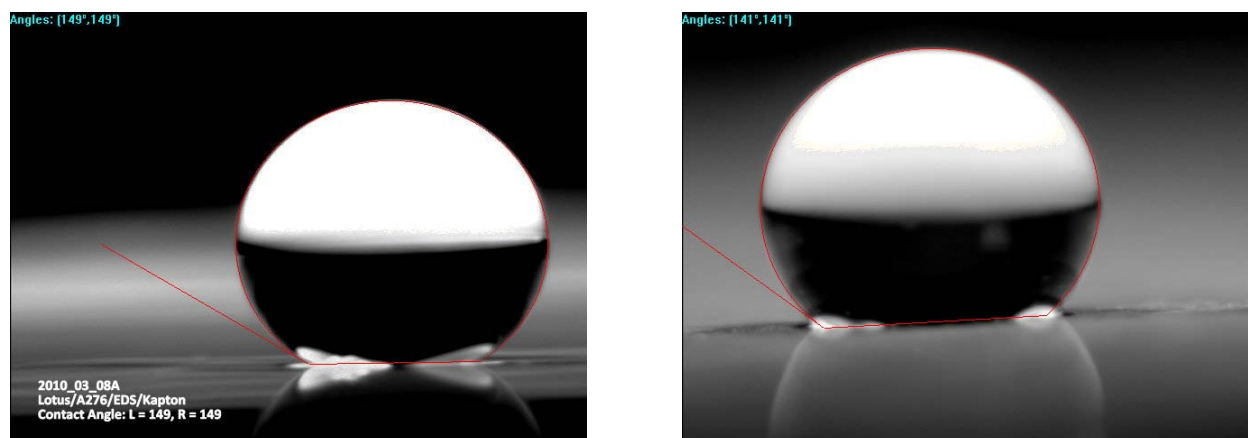
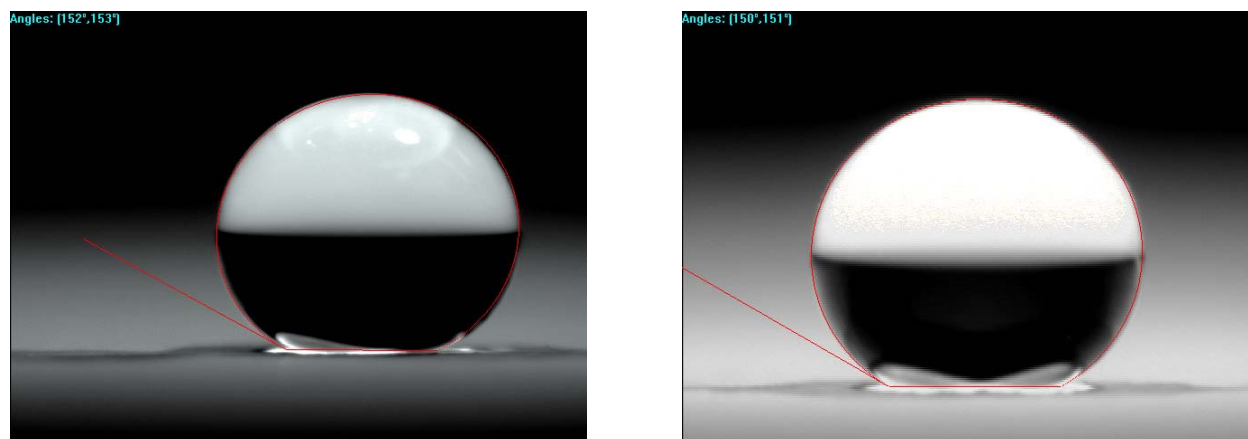


Figure 5: F1T8033011 Contact Angle - Left: Pre-D-RaTS Exposure - Contact Angle =  $153^\circ$ ; Right: Post-D-RaTS Exposure - Contact Angle =  $151^\circ$  ( $151^\circ$  average)



## 4.2 Confocal imaging and surface roughness measurements

Confocal images of all of the samples were captured prior to D-RaTS exposure. These images, at various magnifications, were taken to show how the initial surface architecture of the samples changes with Lotus coating



application and later, with environmental exposure. Also, surface roughness analysis using the confocal microscope's built-in software, analySIS, was performed. These measurements were compared across samples to determine the texturing effect of the Lotus coating application on the surface and to determine the effect of environmental exposure on the surface architecture of the samples. All surface roughness measurements were performed using the 5X objective lens producing one frame (2560 X 1920 microns) or 4.9E6 square microns of analyzable area. In this paper, average surface roughness is described as the average height of all of the peaks and valleys across the analyzable area.

Prior to Lotus coating application, Kapton™ substrates are very smooth with an average surface roughness of 1.7 microns however after the CCVD application of the Lotus coating, the average surface roughness of these samples increased to 11.4 microns. This increase is responsible for the hydrophobic nature of the coating. After D-RaTS exposure of these samples, the average surface roughness decreased to an average of 8.0 microns. This decrease is responsible for the decrease in contact angle that these samples demonstrated post exposure. Control Kapton™ samples which were not exposed during D-RaTS showed a slight change in surface roughness as well however this could be attributed to differences in measurement locations and is negligible.

Prior to Lotus coating application, A276 coated substrates are slightly rougher than just Kapton™ substrates with an average surface roughness of 4.5 microns. After the CCVD application of the Lotus coating, the average surface roughness of these samples increased to 8.2 microns. After D-RaTS exposure of these samples, the average surface roughness decreased slightly by an average of 1 micron. This is a very slight decrease compared to the decrease of demonstrated by the plain Kapton™ samples. This can be attributed to the already textured surface of A276 to which the Lotus coating was applied to. The texture of the A276 allowed the Lotus coating to deposit in existing valleys thus shielding it from some detrimental environmental or handling damage. Since the CCVD method uses a flame spray to apply the Lotus coating, coating is also applied to the existing peaks on the surface of the samples as well. This coating on the peaks is especially vulnerable to handling and environmental exposure damage. It is this peak coating removal that might be responsible for the decrease in contact angle of these samples from the superhydrophobic threshold to the hydrophobic threshold.

Prior to Lotus coating application, Z93 coated substrates are also slightly rougher than just Kapton™ substrates with an average surface roughness of 4.0 microns. After the wet chemistry application of the Lotus coating, the average surface roughness of these samples decreased negligibly by 0.3 microns. Due to the silicate nature of Z93 which is very porous, the Lotus coating was allowed to deposit in existing valleys on the surface. This is similar to the effect seen by the A276 coated samples however unlike the flame spray CCVD method, the wet chemistry method uses a spin coater to apply the Lotus coating. This insures that the coating is mostly deposited in the existing valleys of the surface of the sample thus limiting peak coating removal which has been shown to be detrimental to the A276 coated samples. After D-RaTS exposure of these samples, the average surface roughness also increased negligibly by 0.3 microns. Thus the contact angle for these samples changed the least out of all of the exposed samples, only an average of 2°.

Table 3 below displays the surface roughness measurements of the samples pre-Lotus coating, post-Lotus coating and post D-RaTS exposure as well as the overall change in surface roughness from post-Lotus coating to post exposure. The figures below are 2-dimensional, 5X objective confocal images captured of the samples or representative samples in all of the above listed time frames.

Several samples listed in Table 3 indicate that surface roughness measurements were performed on representative samples. Surface roughness on the large EDS samples could not be performed prior to exposure due to their size and inability to fit in the measuring apparatus. In order to measure the samples, the samples would have had to be bent causing potential damage to both the Lotus coating and the EDS. Smaller representative samples were coated using the samples process as the larger samples and were used in these instances. After exposure, bending the samples was no longer a concern and the samples were able to be bent to fit in the confocal microscope. For the wet chemistry

method applied samples, one sample from each batch was measured for surface roughness instead of the entire batch.

Table 3: Surface Roughness Measurements - Pre-Lotus Coating, Post-Lotus Coating and Post-D-RaTS Exposure

Sample ID	Coating Configuration	Pre-Lotus Coating Surface Roughness (SR <sub>a</sub> ) (μ)	Post-Lotus Coating Surface Roughness (SR <sub>a</sub> ) (μ)	Post-D-RaTS Surface Roughness (SR <sub>a</sub> ) (μ)	Δ Surface Roughness (SR <sub>a</sub> ) (Post-D-RaTS – Post Lotus) (μ)
<b>L1</b>	A276/EDS/Kapton™	4.5*	8.2*	11.5	<b>3.3</b>
<b>L2</b>	A276/EDS/Kapton™	4.5*	8.2*	7.4	<b>-0.8</b>
<b>L3</b>	EDS/Kapton™	1.7*	11.4*	N/A	<b>N/A</b>
<b>L4 – Control</b>	EDS/Kapton™	1.7*	11.4*	17.0	<b>5.7</b>
<b>L5 – Control</b>	EDS/Kapton™	1.7*	11.4*	13.5	<b>2.1</b>
<b>L6</b>	EDS/Kapton™	1.7*	11.4*	7.8	<b>-3.6</b>
<b>L7</b>	EDS/Kapton™	1.7*	11.4*	8.8	<b>-2.6</b>
<b>2010_03_08A</b>	A276/EDS/Kapton™	4.5*	8.2	2.1	<b>-6.1</b>
<b>2010_03_24_D 2</b>	EDS/Kapton™	1.7*	11.4	1.8	<b>-9.5</b>
<b>F1T5033011</b>	Z93/Al	4.0*	3.7*	3.7	<b>-0.1</b>
<b>F1T7033011</b>	Z93/Al	4.0*	3.7*	3.6	<b>-0.2</b>
<b>F1T8033011</b>	Z93/Al	4.0*	3.7*	4.1	<b>0.4</b>
<b>F2T7033011</b>	Z93/Al	4.0*	3.0*	3.2	<b>0.2</b>

\*Surface roughness of a representative sample

Figure 6: Left: A276 Representative Sample – No Lotus Coating - Unexposed - 2D 5X; Right: 2010\_03\_08A with Lotus Coating – Unexposed – 2D 5X; Bottom 2010\_03\_08A – D-RaTS Exposed – 2D 5X

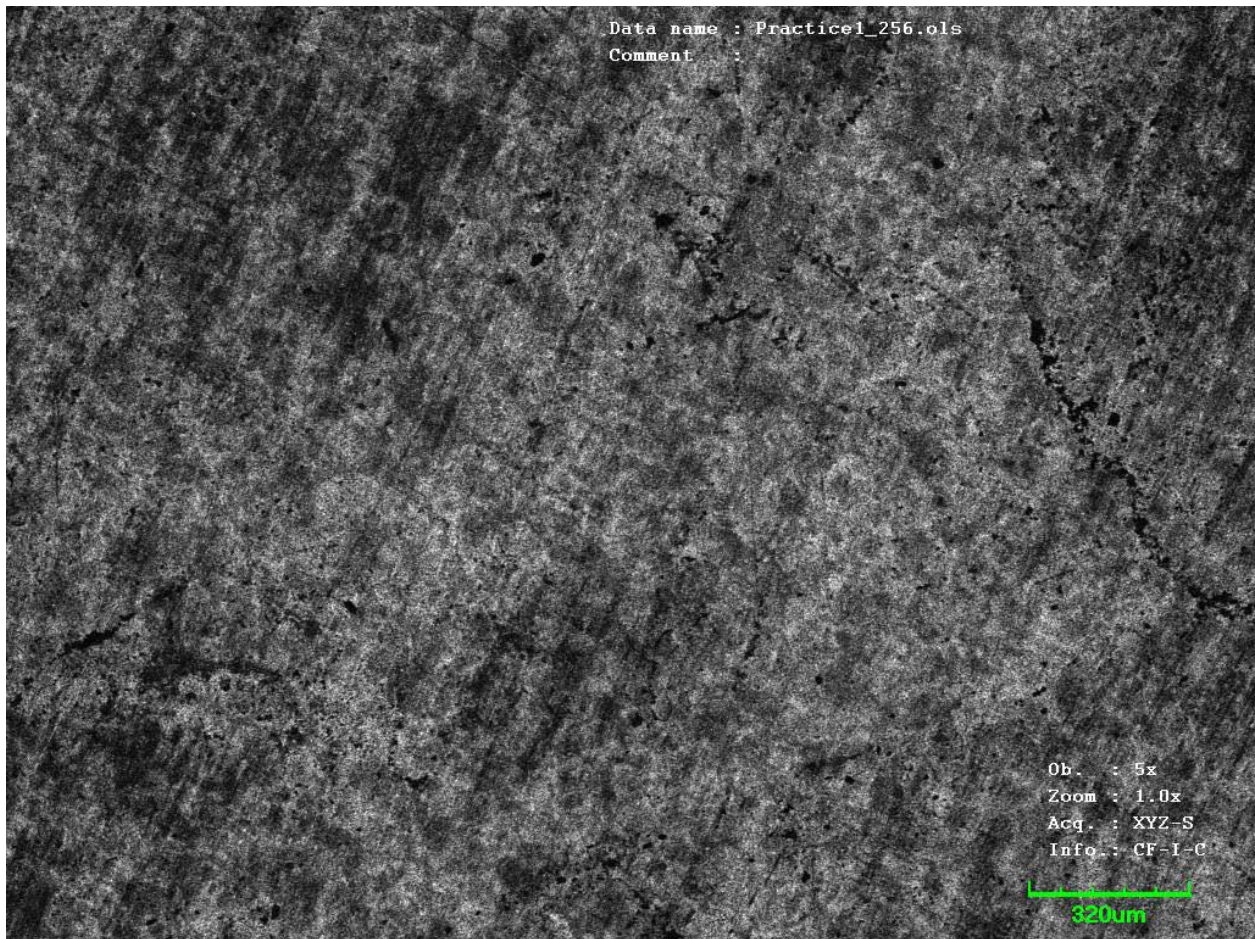
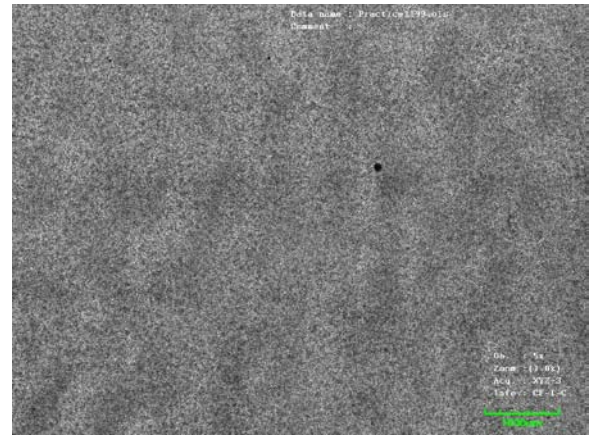
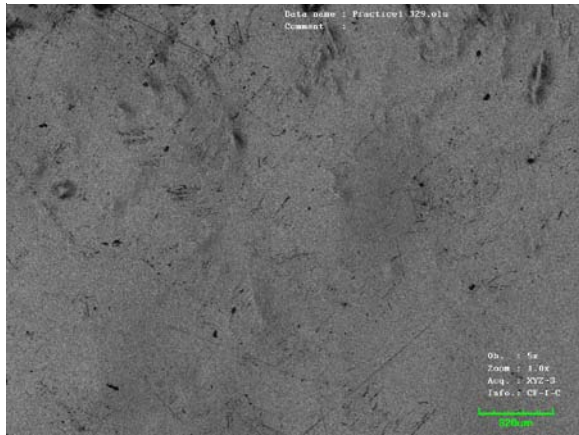




Figure 7: Left: Z93/Al Representative Sample - No Lotus Coating - 2D 5X; Right: Z93/Al with Lotus Representative Sample - 2D 5X; Bottom: F1T5033011 D-RaTS Exposed - 2D 5X

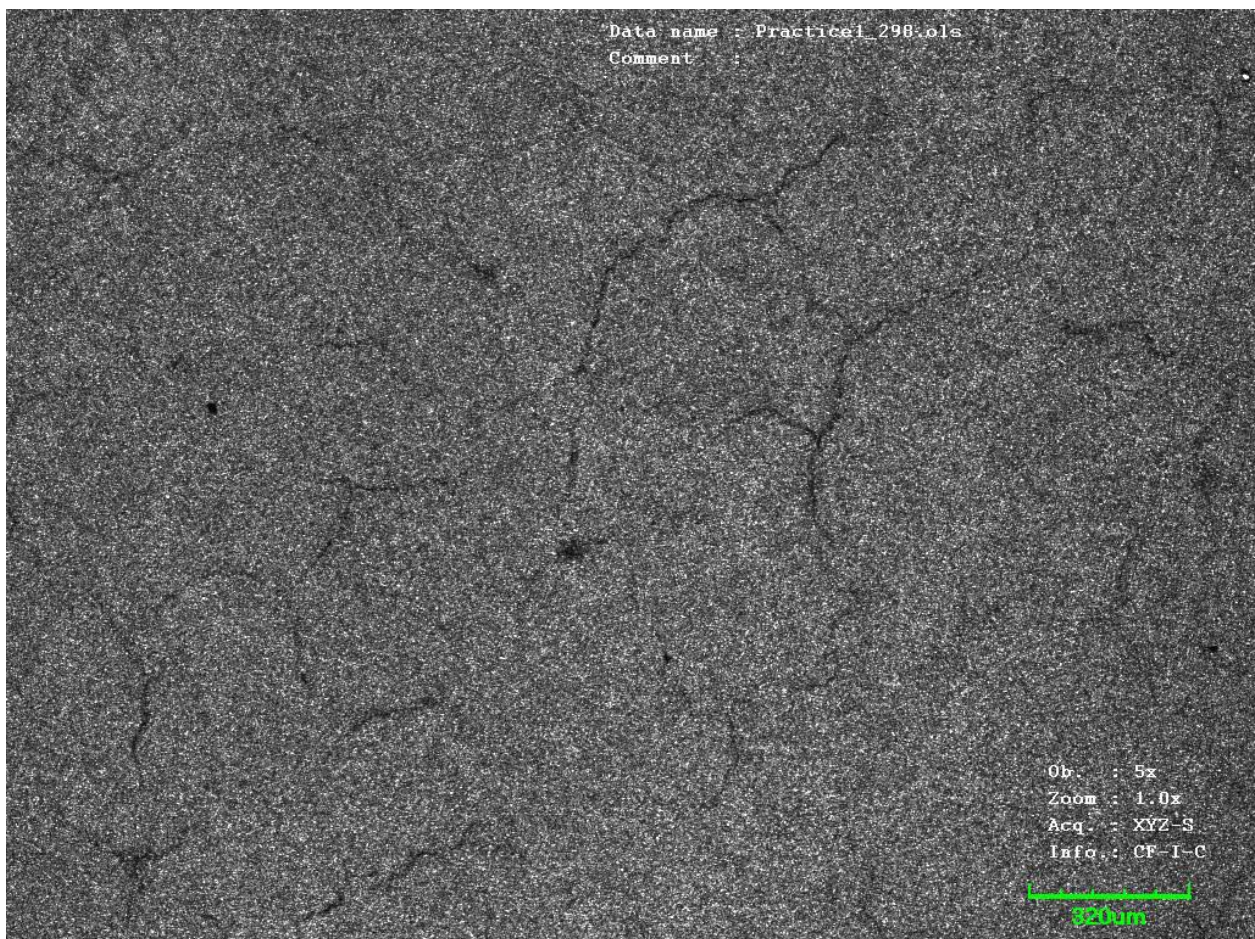
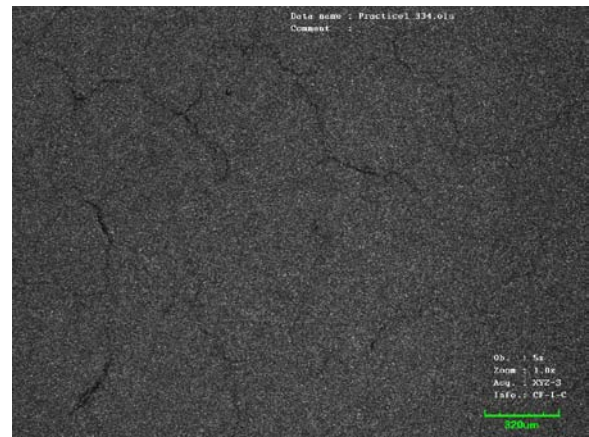
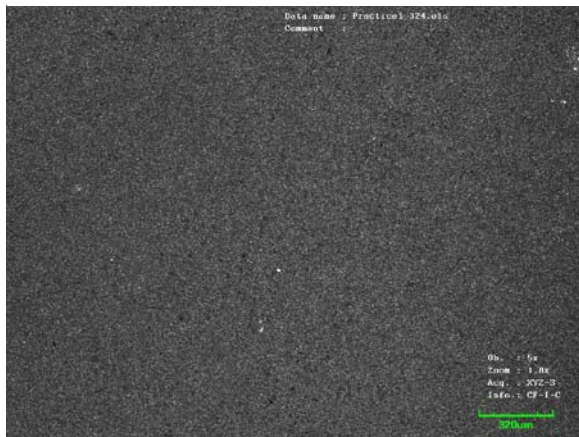




Figure 8: Left: EDS/Kapton(TM) Representative Sample - No Lotus Coating - 2D 5X; Right: 2010\_03\_24\_D2 with Lotus – Unexposed - 2D 5X; Bottom: 2010\_03\_24\_D2 – D-RaTS Exposed – 2D 5X

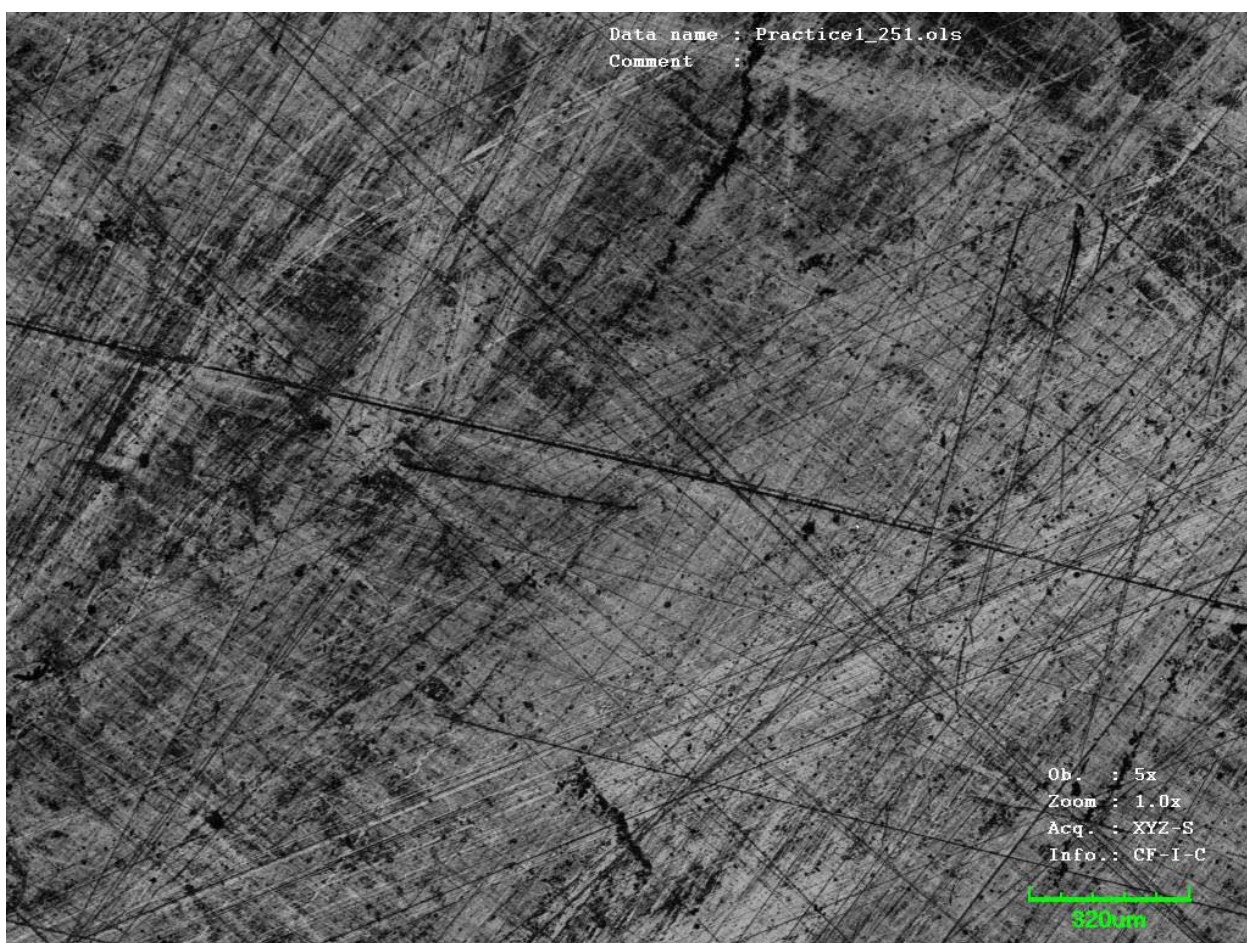
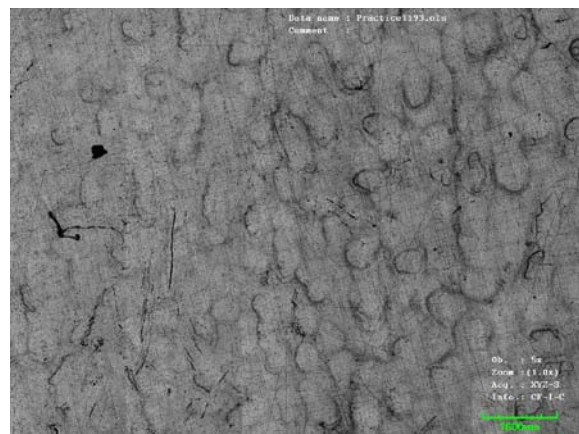
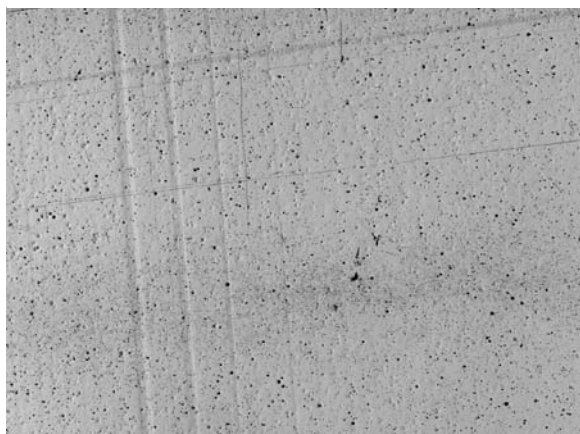
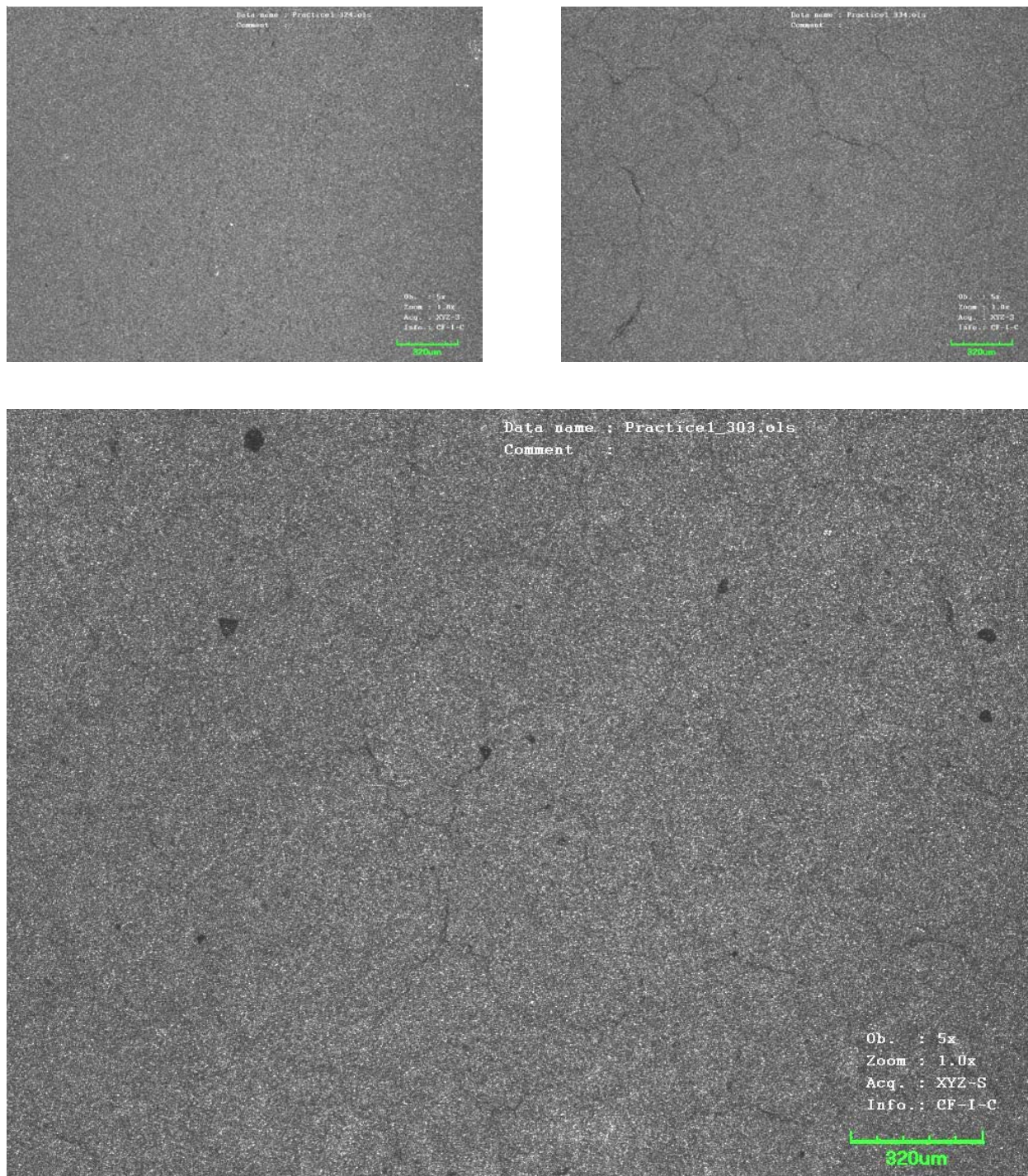




Figure 9: Left: AZ93/Al Representative Sample - No Lotus Coating - 2D 5X; Right: 033011 Representative Sample with Lotus – Unexposed - 2D 5X; Bottom: FIT8033011 – D-RaTS Exposed – 2D 5X



#### 4.3 Solar absorptance measurements

Solar absorptance measurements were taken on all samples prior to Lotus coating application and post Lotus coating application. The following charts show the difference in the reflectance curves from pre-Lotus coating to post-Lotus coating for the three different types of samples exposed at D-RaTS. When applied to existing thermal control

coatings, either Z93 or A276, the Lotus coating, both formulations are almost optically clear between 250 to 2800 nm. This can be seen in Charts 1 and 2.

Chart 1: A276/EDS/Kapton™ - Pre- and Post-Lotus Coating Reflectance Graph

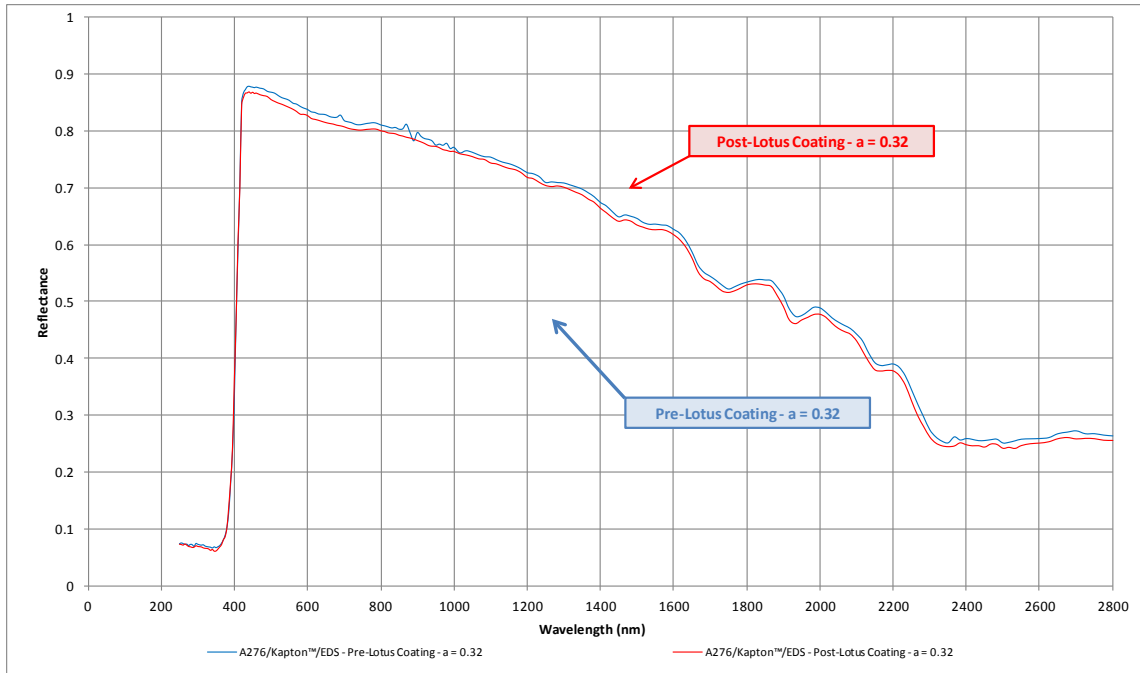
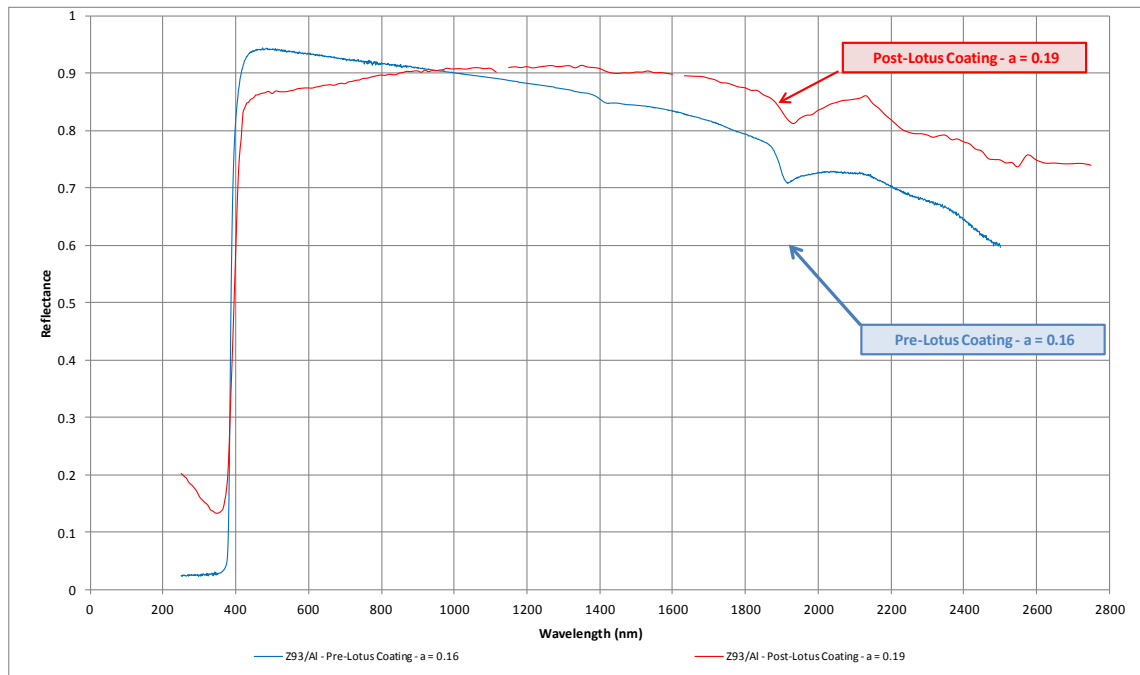


Chart 2: Z93/Aluminum - Pre- and Post-Lotus Coating Reflectance Graph





Solar absorptance measurements were taken several times at the D-RaTS site while the panels were mounted to the side of the PEM. These in-situ measurements were performed on August 31, September 1, and September 11. Measurements were also performed when the panels returned to GSFC on January 9, 2012. These measurements are listed below in Table 4. All of the changes in solar absorptance listed in the last column of Table 4 are within the measurement limitations of the measuring apparatus,  $\pm 0.02$ .

Solar absorptance measurements were not used to characterize the EDS panels without an opaque thermal control coating applied. This is due to their transparency. Different backings present in the laboratory and present in the field would lead to differing solar absorptance measurements which would not be accurate.

Several samples listed in Table 4 indicate that solar absorptance measurements were performed on representative samples. For the wet chemistry method applied samples, solar absorptance measurements were performed on one sample for each batch instead of the whole batch. Also for these samples, in-situ field measurements were not possible due to sample placement on the HDU PEM door.

Table 4: Solar Absorptance Measurements - Pre-Lotus Coating, Post-Lotus Coating and Post-D-RaTS Exposure

Sample ID	Coating Configuration	Pre-Lotus Coating ( $\alpha$ )	Post-Lotus Coating ( $\alpha$ )	D-RaTS 8/31/11 ( $\alpha$ )	D-RaTS 9/1/11 ( $\alpha$ )	D-RaTS 9/11/11 ( $\alpha$ )	Return 01/09/12 ( $\alpha$ )	$\Delta \alpha$ (Return – Post-Lotus Coating)
L1	A276/EDS/Kapton™	0.32	0.32	Only partially exposed		0.32	0.31	-0.01
L2	A276/EDS/Kapton™	0.33	0.33	0.33	0.33	0.33	0.32	-0.002
2010_03_08A	A276/EDS/Kapton™	0.30	0.30	0.28	0.27	0.28	0.31	0.01
F1T5033 011	Z93/Al	0.13*	0.19*	Not feasible for in-situ measurements			0.21	0.02
F1T7033 011	Z93/Al	0.13*	0.19*				0.17	-0.01
F1T8033 011	Z93/Al	0.13*	0.19*				0.18	-0.003
F2T7033 011	Z93/Al	0.13*	0.19*				0.18	-0.01

\*Solar absorptance of a representative sample

#### 4.5 Dino-Lite imaging

Dino-Lite microscopic images were taken on the samples prior to D-RaTS exposure, during exposure, and when the samples were returned to GSFC on September 20, 2011. Several different magnifications were used while taking in-situ and post-exposure measurements. Images in Figure 10 show the surface of samples prior to D-RaTS exposure. The white thermal control coatings appear very clean with very few dust or dirt particles present. The Kapton™ substrate sample in this image also appears to be clean and mostly free of dust particles.

Figure 10: Left: A276 Representative Dino-Lite Image 67X - Pre D-RaTS Exposure; Right: EDS/Kapton™ Representative Dino-Lite Image 67X – Pre D-RaTS Exposure; Bottom: Z93 Representative Dino-Lite Image 67X – Pre D-RaTS Exposure



Figure 11 shows two post D-RaTS exposure images of an A276 coated Kapton™ EDS panel. Both images show contamination and streaking along the surface of the sample. Large dust particles appear scattered throughout the images and smaller dust particles appear in the streaks. Streaking on the Kapton™ EDS samples could have been caused by improper handling during exposure. A wet wipe was used to wipe the panels at one time. Prior to this, the panels were accumulating a large amount of caked-on dust. Dust became caked-on to the panels due to intermittent rain showers experienced at the D-RaTS site. The dust needed to be cleared in order to properly test the capabilities of the EDS. Unfortunately this caused streaking on the surface of the samples and led to small dust particles becoming trapped onto the surface. Despite this streaking, the EDS performed well on all of the panels after manual dust removal. This incident and its affects will be further discussed.

Figure 11: Left: L1 Dino-Lite Image 57X - Post D-RaTS Exposure; Right: L2 Dino-Lite Image 72X – Post D-RaTS Exposure



Figure 12 shows two post D-RaTS exposure images of Kapton™ EDS samples. Streaking can also be seen in these images. Dried water droplets appear in the magnified images on the surface of this sample however very few dust particles appear on these samples.

Figure 12: Left: L4 Dino-Lite Image 62X - Post D-RaTS Exposure; Right: L5 Dino-Lite Image 67X - Post D-RaTS Exposure

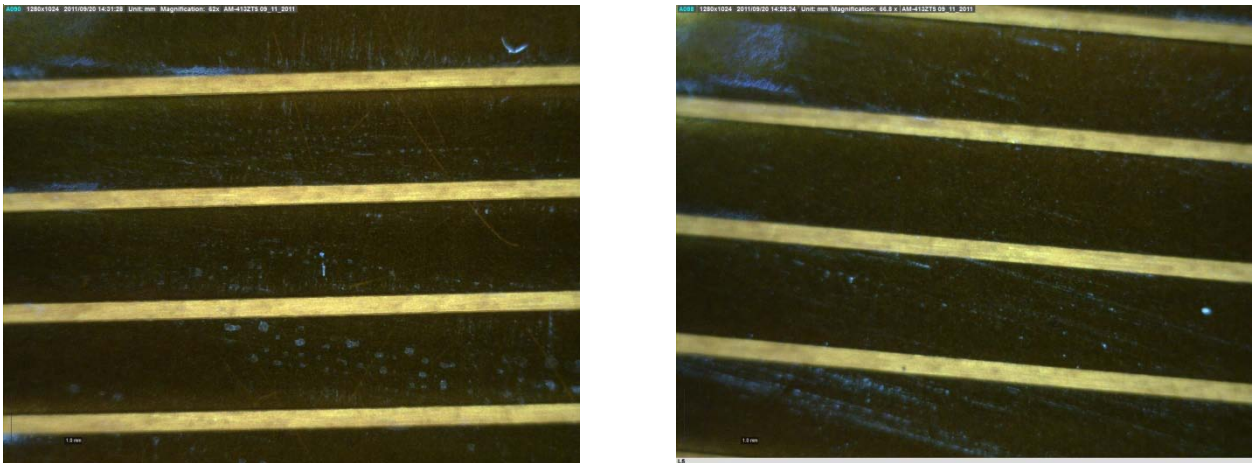


Figure 13 shows two post D-RaTS exposure images of Z93 samples. Due to the porous nature of the Z93, jagged dust particles are more apt to become stuck in the coating. Also, these samples did not have the EDS to help remove lodged dust particles and these samples were also not wiped during the exposure.

Figure 13: Left: F1T7033011 Dino-Lite Image 43X - Post D-RaTS exposure; Right: F1T7033011 Dino-Lite Image 43X – Post D-RaTS Exposure



## 5 HANDLING INCIDENT

Several of the EDS samples were wiped once with a damp wipe during the exposure. The wipe was to remove well-adhered dust particles from the surface. Due to the unpredictable weather at the test site, the samples had been exposed to heavy rain, wind, and hail during their dust exposure. This was not planned or intended. Following this exposure there were several areas on the panels which had extremely well-adhered dust particles. A very light wipe was performed during this time to remove the particles. It was suspected that such a wipe would not harm the hydrophobic properties if performed lightly. According to the contact angle measurements performed before and after the exposure, the wiping only slightly affected the hydrophobic properties although it is impossible to tell which parameter, the wiping or the exposure, actually affected these measurements.

## 6 CONCLUSIONS

GSFC will be collaborating with KSC and JSC again to participate in D-RaTS 2012 by mounting EDS panels on a door of the HDU-DSH. The wet chemistry method of applying the Lotus coating will be further tested during this exposure. Fine-tuning of this method will be pursued at GSFC prior to D-RaTS 2012. Larger samples will be coated with the wet chemistry version of the coating for this exposure as well as Kapton™ EDS panels. Based on in-situ as well as laboratory measurements, both the wet chemistry method applied Lotus coating and the CCVD applied Lotus coating present viable opportunities for passively mitigating dust accumulation. Though both method are viable, the wet chemistry applied method samples consistently performed better than the CCVD applied samples and is verified through the listed post-exposure characterization testing. For future D-RaTS testing the wet chemistry applied method will be exclusively pursued.

## 7 REFERENCES

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